Acta Geographica Debrecina
Landscape and Environment

Volume 9. Issue 2. 2015

Founded in 2007
Péter Csorba – Károly Tar
Department of Landscape Protection and Environmental Geography
Department of Meteorology
University of Debrecen

Publisher:
Institute of Earth Sciences

The issue sponsored by
Meridián Foundation

HU ISSN 1789-4921 (Print)
HU ISSN 1789-7556 (Online)

SCOPE OF THE JOURNAL

ACTA Geographica Debrecina Landscape and Environment Series publishes all the papers in the theme of landscape and environmental researches. Articles of laboratory analysis, GIS methods and reviews are waited. The main subjects of the journal: landscape ecology; landscape evaluation; landscape metrics; land use changes; investigation of environmental elements; human impacts, earth surface processes.

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The journal is indexed/abstracted in CABI, EBSCO, Open J-Gate, Genamic JournalSeek, Ulrichsweb, DOAJ and MATARKA.

Publication information

The journal is published 2 times a year. All manuscripts will be reviewed by 2 independent lectors. After the revision and acceptance the papers will be published at first on the official web page of the journal in online form.

Notice

Available online:

at

http://geo.science.unideb.hu/acta/landsenv/

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Landscape & Environment 9 (2) 2015. 51-58.

HEAVY METAL CONCENTRATIONS IN THE SOILS AND VEGETATION OF THE BÉKE-CAVE WATERSHED (AGGTELEK-KARST, HUNGARY)

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Received 3 June 2015, accepted in revised form 28 December 2015

Abstract
Our research took place on karstic area in Aggtelek National Park in Hungary. The heavy metal content of soils with three different texture and in the plants of the natural vegetation (oak- , hornbeam-, corn leaves, greenery) were studied. Ratio of total (acid soluble) metal contents and bioavailable metal contents of the soils were calculated. Based on these results we determined the mobility of the metals in different soils. Used the metal contents of the soils and the vegetation we set up a sequence of the mobility of the metals between the soil and the most frequent plant species.

Keywords: Aggtelek Karst, soils, vegetation, heavy metal contamination

1. Introduction

This research has been complemented in recent years with studies on the heavy metal load in the soil-plant system. Contaminants in the soil including metals get into the system with the water infiltrating through the soil. In our test area, Aggtelek National Park anthropogenic impact has lately diminished, but traces of former pollution are still present, and contaminants can also enter from the atmosphere through dry and wet deposition from both domestic and transboundary sources. This was observed in the early 2000's (Szőke – Keveiné Bárány, 2003).

On karsts, as in other areas, the vegetation determines the organic matter content and the pH conditions of the underlying soil, which greatly affects the immobilization of metals. The vegetation of nature conservation areas is not harvested each year, so the majority of metals taken up by the plants build up in the soil over the years. If the metals are mobilized, they are returned to the soil, and through the infiltrating water, they contaminate the drinking water supplies of the karstic watersheds. The heavy metals could be present in soils in several forms. There are bound forms, not available for the plants. If the soil's nutrient retention capacity is analyzed, it is not enough to examine the "total" (acid-soluble) metal content of the soils, but we need to determine the amount plants are potentially able to uptake (= "bioavailable" metal content).

The present study examines the heavy metal uptake of plant samples (Sessile oak – Quercus petraea, cornel – Cornus sp., Hornbeam – Carpinus betulus, and the herbaceous layer as a mix) collected from the catchment area of the Béke Cave (Aggtelek-karst) concentrating on the amount of metal that different plants are able to extract from the soil. At the same time we also examined whether the "plant-extractable" metal element content extracted using EDTA solution actually meets the quantities taken up by the different plant species.

2. Showing of the studied area

The study was carried out in the catchment area of the Béke Cave (Aggtelek-karst), in an area of approx. 10 km^2 (Fig. 1.). The surface development of the northern and southern part of the catchment was different. The northern part is formed mainly on well karstifiable Lower Triassic limestone bedrock with real rendzina soils, typical of true karsts. The southern part is a covered karst, where forest soils prevail, formed on Miocene and Pannonian sediments. The rendzina soils covering the surface are red clayey, brown and black rendzinas (Zámbó, 1971). In many places the limestone is covered by a relict red clay layer of variable depth (e.g. in the Red Lake area), which fills the bottom of the dolines, but also appears on the slopes, lower ridges, and rarely even on higher surfaces (Zámbó, 1970). On this layer red clayey and brown rendzina soils were developed with horizontal gradual transition. On the loose Tertiary sediments brown forest soils (brown forest soils with clay illuviation and Ramann brown soils, Luvisols) can be found. In addition, slope sediment soils, and small barren rocky surfaces also occur here

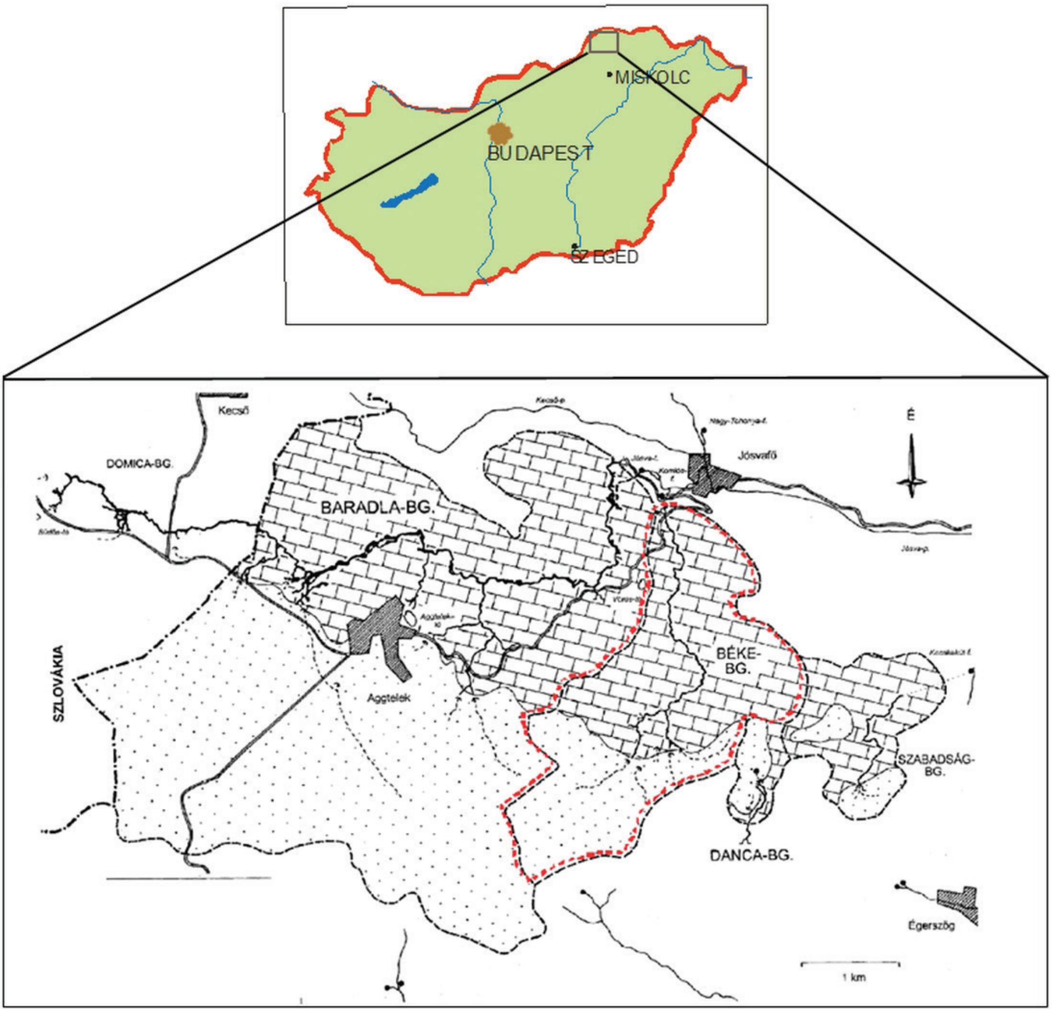

Fig. 1. Aggtelek-Égerszög area's caves with stream and their catchment basin (dotted area = non karstic rocks; rectangle area = karstic rocks). The catchment of Béke cave is indicated with red line (Jakucs, 1985, Balázs, 1961)

(Marosi – Somogyi, 1990; Stefanovits, 1996, 1999; Zámbó, 1998).

The potential vegetation are Turkey and downy oak-dominated forests (Quercetum petraae-pubescentis) and in the eastern part of the watershed sessile oak-hornbeam (Quercetum petraae – Carpinetum betulis) stands. The south-facing rocky slopes support rocky grasslands, ash-lime forests and slope steppes, with sub-montane alder groves along the surface streams and in some places planted coniferous stands. Crop production only occurs in areas adjacent to the settlements and on the border of the karstic and non-karstic areas (Marosi – Somogyi, 1990), mostly in the form of small arable lands.

3. Methods

98 soil samples were collected from different locations from a depth of 20-30 cm. This particular soil depth was chosen because the majority of the examined plants take up nutrients from this section of the soil profile. The plant samples were collected from individuals at the sampling locations. Of the woody plants, the mature leaves of the most common trees: oak, cornel and hornbeam were collected while samples from the mixed herbaceous vegetation were collected with mowing. The soil samples were dried and pulverized, the particle size distribution, pH and organic matter content were determined, and the heavy metal content was measured using two different methodologies. The "total" metal content was determined using a mix of nitric acid-hydrochloric acid-perchloric acid, which takes into solution any type of compound except silicates. The granulometric composition of soil samples were determine according to elutriation method, with this end in view of Atterberg partice size categories.

The "plant-extractable" or "bioavailable" element concentration was determined using the Lakanen-Erviö method. The greenery samples were dried on room-temperature and they were milled. 10 ml cc. HNO_3 was added to 1 g of plant sample, and held in a Gerhardt Kjeldatherm-type digester for 2-3 hours at a temperature of 120 °C, until the mixture became gelatinous. After cooling the sample under a fume hood, 3 cm^3 cc. $HClO_4$ was added and the mixture further heated for one hour at 120 °C. After cooling, the result was washed into a 50 cm^3 measuring flask (HS-08-1783-1:1983). The Cu, Zn, Ni, Co, Fe, Mn and Pb concentrations of the produced solution were determined using the ICP-OES method at the University of Veszprém, Department of Earth and Environmental Sciences.

4. Bioavailable heavy metal concentrations as a function of soil texture

Soils with different texture absorb heavy metals in a different way therefore we examined the ratio of the bioavailable heavy metal concentrations to the total according to soil texture properties (Table 1a., b.). Soil texture varies in the study area; the southern part is covered karst whereas in the northern open karst the heavy metal load can be significantly influenced by soil texture in the case of mobilization.

We can state that the ratio of "available" to "total" heavy metal content is highest in the

Table 1a. The "total" and "bioavailable" heavy metal content of the soils (mg/kg) and their ratio (%)

	Cu			Ni			Zn		
	total	available	*ratio (%)*	total	available	*ratio (%)*	total	available	*ratio (%)*
clay	21.18	8.06	38.06	33.01	1.72	5.21	98.15	6.76	6.89
clayey loam	20.68	7.75	37.47	26.65	1.68	6.32	101.20	7.97	7.88
loam	13.05	8.93	*68.39*	14.93	1.62	*10.88*	87.77	11.58	*13.20*

Table 1b. The “total” and “bioavailable” heavy metal content of the soils (mg/kg) and their ratio (%)

	Co			Mn			Pb			Fe		
	total	avail-able	*ratio (%)*	total	avail-able	*ratio (%)*	total	avail-able	*ratio (%)*	total	avail-able	*ratio (%)*
clay	12.31	4.04	32.79	692.81	343.05	*49.52*	32.86	11.37	*34.61*	30143.93	125.83	0.42
clayey loam	11.46	3.80	*33.16*	867.45	349.87	40.33	34.64	10.82	31.23	25779.82	135.69	*0.53*
loam	8.73	1.97	22.63	878.87	186.30	21.20	15.84	5.16	32.57	17278.52	86.82	0.50

loamy soils for Cu, Ni and Zn.

Only a very small fraction of iron is present in the soil in a plant-available form, in all 3 texture types. For the other examined elements, this ratio is much higher. In the case of Mn and Pb the ratio is highest in clayey soils whereas for Co it is highest in the clayey loam soils. In clay and clayey loam soils 38-45% of copper is in an “available” form, in loamy textured soils its ratio is 70%. This high value is in accordance with data reported in the literature. According to Győri (1984) the total Cu content of the soils in Hungary is usually between 3.2-38 mg/kg while the bioavailable Cu content is between 4-20 mg/kg (Szabó et al., 1987).

Our results concerning the bioavailable Ni content in the area seem to be lower than in literature sources (Fig. 2.). According to Fekete (1988), Szabó (2000) the bioavailable Ni content in Hungary (based on the data of 6000 soils) is 4.43 mg/kg, however compared to the data of Bárány-Kevei et al. (2001) our measurements resulted in lower values. They latter source also mentions an available/acid-extractable Ni ratio of 5-7% in samples from Aggtelek karst while the present results show higher values, especially in loam textured soils.

The total Pb content of the soils is lower than the results reported by Zseni (2001), also from the Aggtelek area (36-96 ppm). Her results for the plant extractable Pb (5-14 mg/kg) are higher, than those of Fekete (1988) who reports a mean of 6.43 mg/kg based on 6000 soil samples from Hungary. Our measurements show a higher available Pb content (32-34 %). The ratio of available/

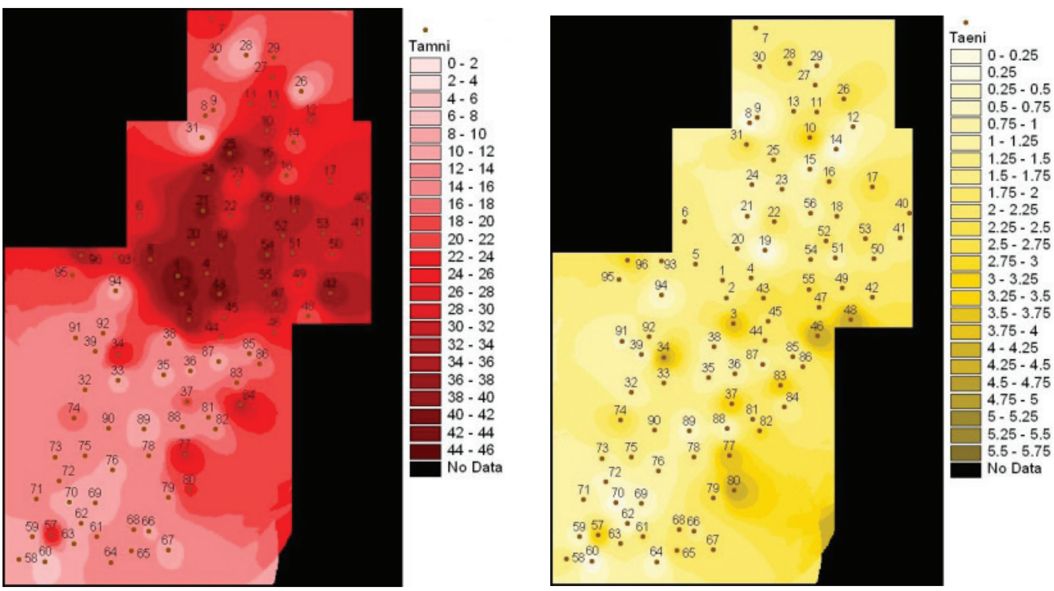

Fig. 2. The distribution of acid soluble (total) and EDTA extractable (bioavailable) Ni concentration on the studied area

total lead content is similar to the results (35%) presented in the study of Szabó (2000).

The acid-soluble Zn content is between 87 and 110 mg/kg, which corresponds to the results of Bárány-Kevei et al. (2001), who examined soil samples from Aggtelek. There are differences between the "available" Zn content, since according to the already mentioned study of Szabó (2000), the plant extractable Zn content is between 3-10 ppm whereas our measurements gave a result of 6.5 mg/kg (in the present study, we measured 6-12 mg/kg). The bioavailable/total Zn ratio (6-16%) that we found is consistent with the findings of Szabó (2000) (12%).

The total amount of Co (Fig. 3.) is also similar to results from earlier literature (Szabó, 2000; Bárány-Kevei et al. 2001) as well as the bioavailable amount (1.7 to 4 mg/kg according to our findings), and the bioavailable/total ratio (literature 21-33%, own measurements 21-32 %). The total Mn content is 780 ppm, the bioavailable amount is 190-420 ppm and the ratio of them varies between 21-49%.

Based on the ratio of the amount of "available" heavy metals to the amount of the "total" heavy metal content, we defined the mobility order (using the means of the ratios in the lower soil layers):

In clay soils: Pb>Mn>=Cu>Co>>Zn>Ni>Fe

In clayey loam soils: Mn>Cu>Pb>Co>Zn>Ni>Fe

In loam soils: Cu>Pb>Mn>Co>Zn>Ni>Fe

The mobility order shows that iron (Fe) is present in the soils in the most bound form, followed by manganese, lead and copper. Cobalt, zinc and nickel are moderately mobilized (all 3 are in a similar situation in the mobility order).

5. Comparative analysis of the heavy metal content of soil and plant samples

At first we tried to define how the heavy metal content of the examined species answer compared to the total heavy metal content of the soil samples taken from the same location. To do this, we determined the value of the soil-plant transport coefficient. Then we calculated the ratio (%) of the heavy metal content of the plants and the "total" heavy metal content measured in the soil (Table 2.).

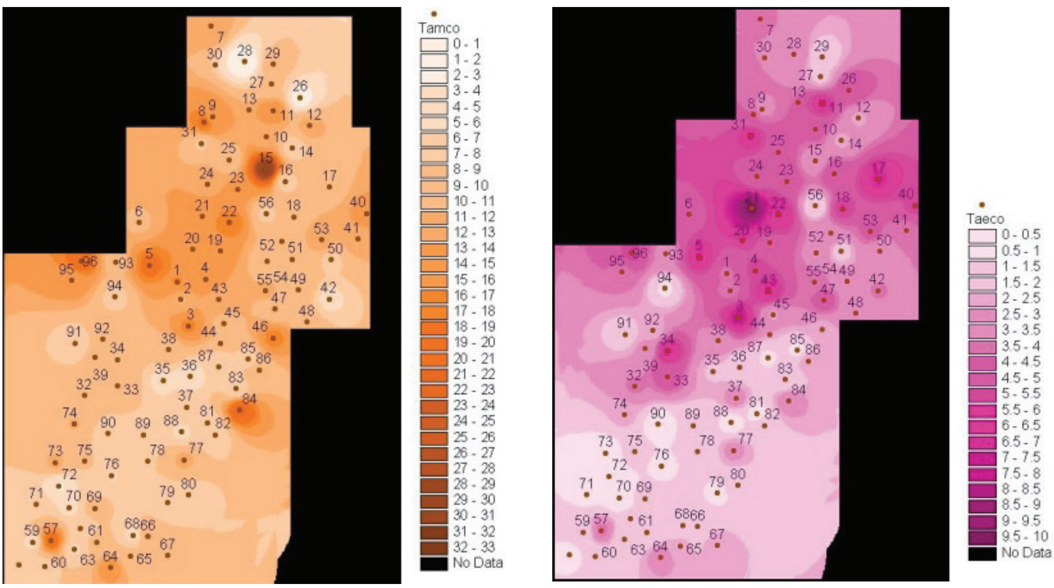

Fig. 3. The distribution of acid soluble (total) and EDTA extractable (bioavailable) Co concentration on the studied area

Table 2. The ratio of the heavy metal content of the plants and the “total” heavy metal content measured in the soil (%)

	oak (*Quercus petraea*)						hornbeam (*Carpinus betulus*)					
	metal	clay	metal	clayey loam	metal	loam	metal	clay	metal	clayey loam	metal	loam
1.	Fe	0.002	Fe	0.002	Fe	0.004	Fe	0.004	Fe	0.004	Fe	0.007
2.	Pb	0.054	Ni	0.071	Pb	0.052	Pb	0.053	Pb	0.065	Co	0.062
3.	Ni	0.099	Co	0.091	Co	0.068	Ni	0.057	Ni	0.196	Pb	0.086
4.	Co	0.280	Pb	0.129	Ni	0.225	Co	0.090	Co	0.212	Ni	0.355
5.	Cu	0.372	Zn	0.227	Zn	0.312	Zn	0.293	Zn	0.268	Zn	0.500
6.	Zn	0.378	Cu	0.328	Cu	0.554	Cu	0.483	Cu	0.335	Cu	0.760
7.	Mn	1.734	Mn	2.026	Mn	3.011	Mn	1.446	Mn	1.950	Mn	3.802
	cornel (*Cornus sp.*)						herbaceous layer, mixed					
	metal	clay	metal	clayey loam	metal	loam	metal	clay	metal	clayey loam	metal	loam
1.	Fe	0.003	Fe	0.004	Fe	0.005	Fe	0.006	Fe	0.005	Fe	0.009
2.	Pb	0.029	Co	0.028	Co	0.029	Ni	0.050	Ni	0.057	Co	0.212
3.	Ni	0.040	Pb	0.031	Pb	0.049	Co	0.190	Mn	0.155	Ni	0.247
4.	Co	0.040	Mn	0.051	Mn	0.144	Mn	0.237	Co	0.311	Mn	0.300
5.	Mn	0.052	Ni	0.078	Ni	0.440	Zn	0.289	Zn	0.363	Zn	0.540
6.	Zn	0.208	Zn	0.211	Cu	0.442	Cu	0.401	Cu	0.660	Cu	0.761
7.	Cu	0.272	Cu	0.241	Zn	0.470	Pb	26.651	Pb	21.234	Pb	59.985

The serial numbers of Table 2. mark the order calculated on the basis of the maximum values. The highest value of each metal in a particular plant according to soil type is indicated in italics. The table shows that the heavy metal content of the plants compared to the total heavy metal content of the soils is usually the highest in the case of loam textured soils. This suggests that loamy texture provide favorable conditions for the plants to uptake metal. Of the arboreal species the tendencies are quite clear for the hornbeam and cornel, whereas in the case of oak the value is in some cases highest in the other soil types. The Table 3. compares data from the literature with our own measurements.

Based on the soil-plant transport coefficient, we defined the mobility order of the examined heavy metals in the plants on the different soil types:

Clay soils:

Oak: Fe<Pb<Ni<Co<Zn=Cu<Mn

Hornbeam: Fe<Pb=Ni<Co<Zn<Cu<Mn

Cornel: Fe<Pb<Co=Ni<Mn<Zn<Cu

Mixed herbaceous: Fe<Ni<Co<Mn=Zn<Cu<Pb

Clayey loam soils:

Oak: Fe<Ni<Co=Pb<Zn<Cu<Mn

Hornbeam: Fe<Pb<Ni<Co<Zn<Cu<Mn

Cornel: Fe<Co<Pb<Mn<Ni<Zn=Cu

Mixedherbaceous: Fe<Ni<Mn<Co<Zn<Cu<Pb

Loam soils:

Oak: Fe<Pb=Co<Ni<Zn<Cu<Mn

Hornbeam: Fe<Pb<Ni<Co<Zn<Cu<Mn

Cornel: Fe<Co<Pb<Mn<Ni=Cu<Zn

Mixed herbaceous: Fe<Co<Ni<Mn<Zn<Cu<Pb

According to the soil-plant transport coefficients it is clear that iron is the least extractable element in the examined soils. The iron content of the plants does not exceed

1% in any case. The lead, cobalt, and nickel values of 13, 31 and 44% respectively can be considered moderate. These are followed by zinc and copper with 54% and 76% content in the plants. The most mobile metal on the basis of the soil-plant system of transport coefficients is manganese. Plants are able to uptake and accumulate more of this metal than the soils' total content. The mobility order based on our results is different from those published in the literature (Kloeke et al., 1994; Szabó, 2000; Szabó, 2008). Especially manganese shifts towards the end of the line in our study (towards better availability) especially in the case of the trees; the mobility order of cornel is similar to those in the literature. For herbaceous plants lead was found to be one of the most mobile elements (at the end of the mobility order) for all soil types.

Table 3. The transport coefficients of heavy metals in the soil-plant system based on literature data and own results

	Soil-plant transport coefficient		
	Kloeke et al.*	Szabó (2000)	this study
Cu	0.1-10	0.1-1.9	0.24-0.76
Ni	0.1-1.0	0.1-0.3	0.04-0.44
Zn	1-10	0.5-1.7	0.21-0.54
Co	0.01-0.1	<0.01-0.1	0.03-0.31
Mn	-	0.01-0.2	0.05-3.80
Pb	0.01-0.1	<0.01-0.1	0.03-0.13
Fe	-	0.001-0.03	0.002-0.009

(*Chojnacka et al. 2005)

6. Conclusion

In the present study we showed that in karst areas the ratio of plant-extractable ("available") to acid-soluble ("total") heavy metal content differs according to soil texture. In the loam soils (situated in the southern part of the study area, on the covered karst) copper, nickel and zinc show the highest available/total ratio, in the clay soils (mainly occurring in the open karst area) manganese and lead, whereas in clayey loam soils iron and cobalt can be found in the most available form. The examination of the metal content of some plant species showed that in the case of hornbeam, cornel and the mixed herbaceous layer most of the examined heavy metals can be found in the highest concentrations on the loam soils, except for cobalt. In the case of hornbeam the mobility order based on the soil-plant transport coefficient is the same for each of the three soil types. For the arboreal species (oak, hornbeam) the soil-plant transport coefficient of manganese is behind in the mobility order while those of cornel and the mixed herbaceous layer are in the middle. The herbaceous layer takes up lead in high proportions on all three soil texture types. This indicates that lead exposure on the karst must be prevented by all means, due to the risk presented by high mobility in these areas.

7. References

Bárány, I. (1985): Ökologische Untersuchung der Karstdolinen unter besonderer Berücksichtigung des Mikroklimas. Acta Geographica Univ. Szegediensis. Tom. 25: pp. 109-130.

Bárány-Kevei, I. (1998): The geo-ecology of the Hungarian karsts. Cave and Karst Science 25: pp. 113-117.

Bárány-Kevei, I. – Mezősi, G. (1999): The relationships between soil chemistry and the heavy-metal content of vegetation on karsts. In: Bárány-Kevei, I. – Gunn, J. (eds.). Essays in the Ecology and Conservation of Karst. Acta Geographica Szegediensis 36. Special Issue pp. 47-53.

Fekete, A. (1988): Nem esszenciális (toxikus) elemek a hazai talajokban. In: Mikroelemek az agrárkörnyezetben MAE Környezetvédelmi Szakosztály Ankétja. Gödöllő. Szerk. Fekete J. pp 93-112. In: Debreceni, B ., Czech, R: A műtrágyázás hatása a talajok könnyen oldható mikroelem-tartalmára. Agrokémia és Talajtan Tom. 40 (1-2): pp. 140-152.

Gillieson, D. – Smith, D. I. (1989): Resource Managenent in Limestone Landscapes: International Perspectives. Scpecial Publication 2, Department of Geography and Oceonography, University College, Australian Defence Force Academy, Canberra 260 p.

Győri, D. (1984): A talaj termékenysége. Mezőgazdasági Kiadó. Budapest In: Szabó S. A. – Regusiné Mőcsényi Á. – Győri, D. – Szentmihályi 1993. Mikroelemek a mezőgazdaságban I. Mezőgazdasági Kiadó. Budapest. 235p.

Bárány-Kevei, I., Goldie, H., Hoyk, E., Zseni, A. (2001): Heavy metal content of some Hungarian and English karst soils. Acta Climatologica Szegediensis Tom 34-35: pp. 81-92.

Jakucs, L. (1971). A karsztok morfogenetikája. Földrajzi Monográfiák 8. Akadémiai kiadó, Budapest. 310 p.

Jakucs, L., Keveiné Bárány, I., Mezősi, G. (1983):A karsztkorrózió korszerű értelmezése Földrajzi Közlemények 31: pp. 307-218.

Kaszala, R. – Bárány-Kevei, I. – Polyák, K. (2004): Further dates of heavy metal content on the soil and vegetation of Aggtelek Karst (Hungary), Acta Carsologica, 33 (2): pp. 169 - 180.

Kevei Bárány, I. – Zámbó, L. (1986): Study of the relationship between bacteria activity in karstic soils and corrosion. Annales Universitatis Scientiarum Budapestinensis de Rolando Eötvös Nominatae. Tomus 20-21: pp. 325-333.

Keveiné Bárány, I. – Zseni, A. – Kaszala, R. (2000): A talaj és növényzet nehézfém-tartalmának vizsgálata karsztos mintaterületen. Karsztfejlődés 7., BDF Természetföldrajzi Tanszék, Szombathely. pp. 297-315.

Kloeke, A. – Sauerbeck, D. R. – Vetter, H. (1994): In Changing Metal Cycles and Human Health. Ed. Nriagu, J. Springer-Veriag. Berlin 113 p.

Marosi, S. – Somogyi, S. (1990): Magyarország kistájainak katasztere I-II. MTA Földtudományi Kutató Intézet, Budapest. 985 p.

Stefanovits, P. – Filep Gy. – Füleky, Gy. (1999): Talajtan. Mezőgazda Kiadó p. 31.

Stefanovits, P. (1996): Talajtan Mezőgazda Kiadó pp. 131-132.

Szabó, Gy. (2000): Talajok és növények nehézfémtartalmának földrajzi vizsgálata egy bükkaljai mintaterületen, Studia Geographica, Institutum Geographiae, Universitas Debreceniensis, pp. 144-165.

Szabó, Sz. – Posta, J. – Gosztonyi, Gy. – Mészáros, I. – Prokisch, J. (2008): Heavy metal content of flood sediments and plants near the River Tisza. AGD Landscape & Environment 2 (2): pp. 120-131.

Szőke, E. – Keveiné Bárány, I. (2003): Karsztvíz vizsgálatok az aggteleki karszton, különös tekintettel a nehézfém szennyezésre. Karsztfejlődés 8. Szombathely, pp. 173-185.

Urushibara-Yoshino, K. (1991): The regionality of solution rate of limestone tablets in karst areas of Japan. Institute for Applied Geography, Komazawa Oniversity, Regional Views 4: pp. 107-117.

Urushibara-Yoshino, K. (1993): Human impact on karst soils Japanese and other examples. – Catena, Supplement (25) Clemingen, pp. 219-233.

Urushibara-Yoshino, K. – Kashima, N. – Enomoto, H. – Kuramoto, T. – Kina, H. – Nakahodo,T. – Higa, M. (1999): Inter-annual variation of limestone solution rates in Japan. In :Bárány-Kevei I. – Gunn J. (Eds.) Essays in the ecology and conservation of karst. Special Issue of Acta Geographica Szegediensis, Acta Geographica 36: pp. 201-211.

Zámbó, L. (1970): A vörösagyagok és a felszíni karsztosodás kapcsolata az Aggteleki-karszt délnyugati részén. Földrajzi Közlemények 18. kötet 281-293.

Zámbó, L. (1998): Felszínalaktani jellemzés In: Baross G. (Ed): Az Aggteleki Nemzeti Park Mezőgazda Kiadó. Budapest. pp 95-118.

Zseni, A. (2001) Nehézfém vizsgálatok az Aggteleki karszt, a Bükk-fennsík és a Nyugat-Mecsek karsztjának mintaterületén In: Farkas, Gy. – Zábrádi, Zs. (szerk.): Földrajzos Doktoranduszok VII. Országos Konferenciája. ELTE TTK Földrajzi Tanszékcsoport. Budapest. Paper 10: 9 p.

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PREDICTION OF INDUSTRIAL LAND USE USING LINEAR REGRESSIONAND MOLA TECHNIQUES: A CASE STUDY OF SILTARA INDUSTRIAL BELT

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Received 14 October 2015, accepted in revised form 28 December 2015

Abstract
The Siltara Industrial belt is an important industrial pocket of Chattisgarh state located in the northern part of the Raipur city, which is rapidly growing. In this process spatial, cultural, political and administrative factors are controlling its rate, direction and pattern. The Simple Linear Regression (SLR) and Multi-Objective Land Allocation (MOLA) techniques, which are embedded in SPSS and Idrisi Kilimanjaro software respectively, and have been used for the estimation of future scenario of the industrial growth. In this model, a suitable platform has been prepared in which future industrialization has been estimated by integrating physical, social, cultural factors and land acquisition policy. In this article, results have revealed that industrialization has occurred very fast during last one decade. The industrial land was 6.15 km^2 in 2001 and 18.725 km^2 in 2011 and estimated as 31.30 km^2 in 2021 and 43.87 km^2 in 2031 using SLR. The rapid industrial growth is very critical issues for agrarian society and fresh environment. This model very accurately estimating (overall accuracy=95.39%, Kno=97.24%, agreement=98.63 %) the future growth of industrial land. This work will be useful to the planners and policy makers of private and government sectors to regulate the sustainable planning practices and smart decision-making.

Keywords: GIS, Multi-Objective Land Allocation (MOLA), Simple Linear Regression (SLR), industrial belt growth

1. Introduction

Industrialization is the process of the expansion of industrial area, which was arising, with the advancement of human civilization through economic growth. This scenario gives birth to the urbanization which jointly termed as industrialization-urbanization process. The dynamics of this process was triggered through the economic demand to sustain the rapid population growth in one side and enhancing the alarming change in agricultural land into industrial land uses and healthy environment into polluted environment is the another side (Downing et al., 1999; Chaitanya, 2007 ; Lu et al., 2011; Singh et al., 2016). In this regards, the China and India experiencing sole giants in the rest of the countries of the World (FAO, 2006). Recently, this scenario is a challenge to the existence of the human society in response to food security and climate change (Li et al., 2011; Rutten al., 2014). Besides, Chhattisgarh is one of the rapid industrialized states in India which spread over various spatial pockets. The Siltara industrial belt is an important industrial pocket of this state located in the northern part of the Raipur city and experiencing several changes in landscape and its surrounding environments. During last several decades it was observed that the several simulation models like Cellular Automata (Batty, 1997; Clarke and Gaydos, 1998; Li and Yeh, 2000), Markov Chain (Lo´pez et al., 2001; Weng, 2002; Wu et al., 2006),CA-Markov (Memarian et al., 2012; Ahmed and Ahmed, 2012; Singh et al., 2015), MLP-Markov (Tewolde and Cabral, 2011; Ahmed and Ahmed, 2012; Megahed et al., 2015) have been used by the researchers for simulation of land use and land covers however none of them were ever conducted the study on the integration of statistical model like Simple Linear Regression with the Spatial model like MOLA for the simulation. This article aims to identify the present and future scenarios of industrial growth through advance geo-simulation model namely Multi-objective Land Allocation (MOLA) and Linear Regression. MOLA is a spatial overlay technique that converts statistical entity into spatial entity and Linear Regression which extract statistical entity based on causally two interdependent variables. This advance geo-simulation model may enhance the result as compared to traditional methods and thus it will be very fruitful to various landscape and economic planners in government and private sectors for policy making and implementation.

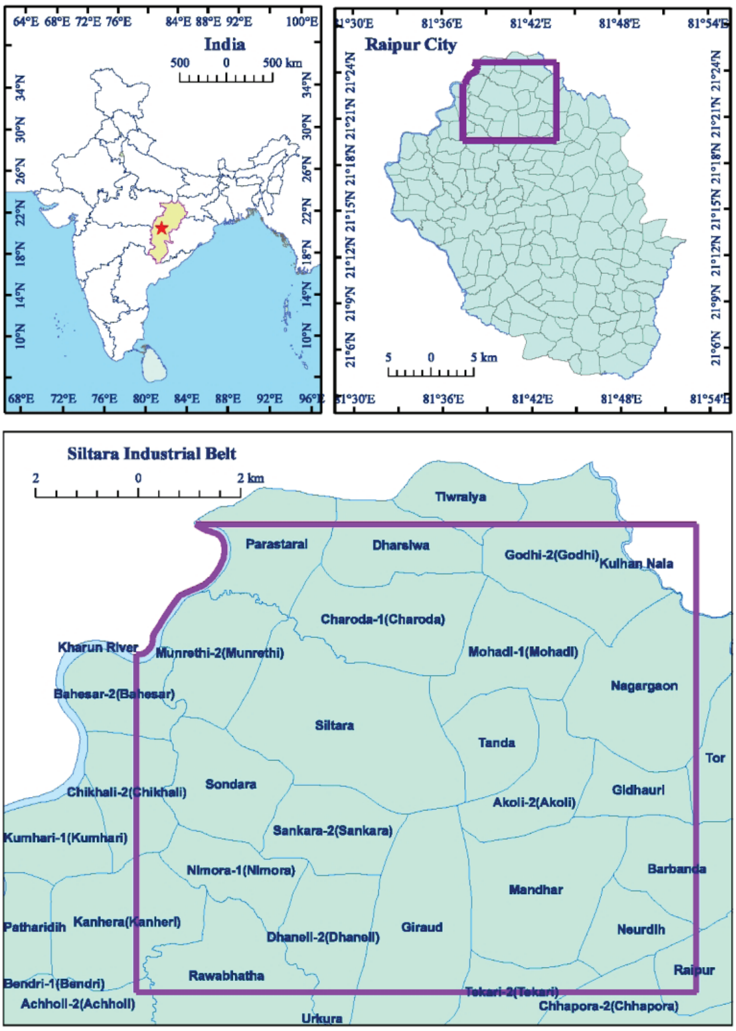

Fig. 1. Location of Siltara industrial belt

2. Study area

The Siltara industrial belt is located in the northern part of the Raipur City, India and extends in between 21°19 N to 21°24' N latitude and 81°37' E to 81°43'E longitude covering with an area of 99.38 km2 at 280 m height from above mean sea level (Fig. 1.). The Kharun is the main perennial river which flowing from south to north in the western part of this industrial belt. The Bilaspur-Howrah national highway (NH-200) and Howrah- Nagpur rail line connects the industrial belt with Kolkata and Mumbai metropolitan cities for trade and commerce.

3. Database

This article is based on the application of high resolution earth observation satellite datasets such as IRS-1C (LISS-III, GSD 23.5 m, dated- 2001), IRS-1D (PAN, GSD 5.8 m, dated-2001) and Cartosat-1 (PAN, GSD 2.5 m, dated- 2011) and Resousesat-1(LISS-IV, Multispectral, GSD 5.8 m, dated- 2011). These datasets have been collected from National Data Centre (NDC), National Remote Sensing Centre (NRSC), Hyderabad (A.P).The Survey of India topographical sheets (64G/11 and 64G/12, 2005 modified) have been collected from the Survey of India, Regional office, Raipur, India. The details of satellite datasets are given in table 1.

The referenced datasets such as Bhuvan Geoweb data collected from the website of National Remote Sensing Centre, Hyderabad, India (2011), the Google earth satellite imageries (2011) and field survey data (ground truthing) using GPS.

4. Methods

This study has been carried out through several steps that explained in Fig. 2.

Pre-processing

The pre-processing of satellite imageries such as the geometric correction (UTM projection, zone-44north, datum WGS84) has been carried out using Indian topographical sheets, 64G/11 and 64G/12. The radiometric correction has been done using the Improved Dark Object Subtraction Approach (Mustak, 2013) and the image fusion has been done using the Wavelet transformation. All these pre-processing tasks have been carried out to enhance the spatial and spectral information for the better interpretation and accuracy. However, subset and mosaicking have been carried out for the delineation of area of interest. The whole pre-processing tasks have been carried out using Erdas Imagine 9.1 software.

Thematic mapping

The onscreen visual interpretation technique has been adopted for the preparation of land use maps of 2001 and 2011 using satellite datasets of 2001 and 2011 by incorporating with the referenced datasets such as survey of India topographical sheets (64G/11 and 64G/12, 2005 modified), Bhuvan Geoweb data (2011), Google earth

Table.1. Satellite imageries and referenced datasets, 2001-2011

Satellite datasets			Referenced datasets	
Satellite/Sensors	Spatial Resolution (metre)	Year	Data types	Year
IRS-1C (LISS-III)	23.50	2001	Topographical sheet 64G/11 and 64G/12	2005
IRS-1D (PAN)	5.80	2001	Bhuvan Geoweb data	2011
Cartosat-1 (PAN)	2.50	2011	Google Earth satellite imageries	2011
Resousesat-1 (LISS-IV)	5.80	2011	Ground truthing using GPS	2011

satellite imageries (2011) and field survey data (2011). The definition of land use and land cover classes and preparation of geodatabase are based on the standard framework of National Urban Information System (National Remote Sensing Agency, 2008). The land use and land cover maps of the Siltara industrial belt have been prepared using the Arc GIS 9.3 software.

Resampling and Data transformation

In this study, the different types of vector layers have been converted into raster file format which are the pre-requisites for simulation modelling. The land use map of 5.80 m resolution (2001) has been resampled similar to the land use map of 2.50 m resolution because uniform dimension and spatial resolution are the pre-requisites for this simulation modelling (Eastman, 2012). In this study, the Erdas Imagine 9.1, Idrisi Kilimanjaro and Arc GIS 9.3 have been used.

Future Growth Simulation Modelling

The future growth simulation modelling of industrial land has been carried out by integrating two sub-models such as:

Simple Linear Regression

The Simple linear Regression (SLR) has been used for the estimation of future growth of industrial land, which provides statistical outcomes (Table 2.) using formula 1.

$$y=a+bx \quad [1]$$

In this formula.1, 'y' denotes to dependent variables while 'x' denotes to independent variables and 'a' is intercept while 'b' is slope. In this model, the industrial land use denotes to dependent variable while time denotes to independent variable and 'a' and 'b' are coefficients. The industrial land use of 2001 and 2011 has been used to predict the future industrial land of 2021 and 2031 (Table 2.). This modelling has been carried out suing SPSS version 19.

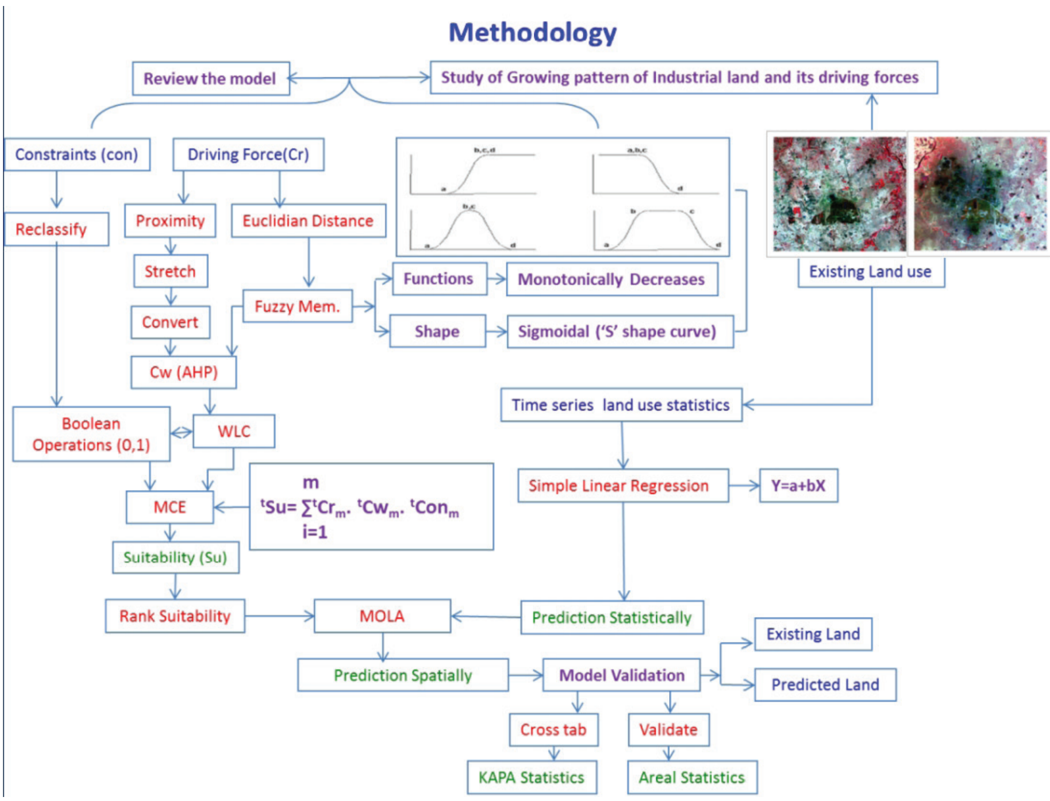

Fig. 2. Methodological flowchart for the Simulation Model, 2001-2031

Multi-Objective Land Allocation

MOLA has capability to allocate the land on space based on the competitive land use demands and numbers of spatial suitability and constraints in which conflicts that has derived in the simulation process are automatically resolved by this model (Houet and Hubert-Moy 2006; Eastman, 2012). In this model, industrial land, which has been predicted for future using SLR, has been used as an input in MOLA to fulfil the competitive land use demands during simulation. This model has been calibrated through several steps. Firstly, criteria and constraints has been defined in this simulation. In this process, the criteria which are termed as driving forces that provides suitable spatial allocation environments while constraints are strict limiting space in which allocation of land in future is strictly prohibited. In this article, suitable criteria are industrial Euclidian distance, road Euclidian distance, vacant land/layout, barren land and fallow land (Fig. 3) while constraints are residential land, transportation land, main river proximity (500 m), other waterbodies proximity (20 m) and main waterbodies (Fig.4).

Secondly, criteria weight optimization has been carried using Analytical Hierarchy Process (AHP) through Matlab programming. This step is very important for the land suitability analysis in which judgement has been made on several criteria based on Saaty's 9 point rating scale to derived criteria weights (Saaty, 1980; Mustak et al., 2015).In this judgement, the results is very consistent as defined having Consistency Ratio as 0.0152 (CR=<0.10 acceptable, λ_{max} = 5.0681, n=5) because for consistent matrix λ_{max}=order of matrix (n) or $\lambda_{max} \geq n$ (Saaty, 1980; Memarian et al., 2012). Thirdly, criteria layers standardization has been carried out in this study which is very important for the land suitability mapping. In this process, different criteria layers have been standardized at scale of 0-255 using monotonically decrease and user-defined fuzzy membership functions which are pre-requisites for the simulation process. This process has been carried out in Idrisi Kilimanjaro software, Clark Lab, USA.

Fourthly, land suitability and suitable rank mapping has been carried for future land allocation of industrial land. The land suitability mapping has been done using the Multi-criteria Evaluation (MCE) module, which integrated with the Weight Linear Combination (WLC), and Boolean Intersection (BI) algorithms of Idrisi Kilimanjaro Software. The index of land suitable map varies in between 0 to 255 in which 255 explained highest suitability while 0 explained lowest suitability. Such land suitability map is an input for the rank suitability mapping. The Rank module of descending order algorithm has been used to prepare rank suitability mapping (Fig. 5.) using Idrisi Kilimanjaro Software.

The index of rank suitability map explained that the lowest value represents high suitability while highest value explained the less suitability.

Finally, competitively land allocation has been carried out using MOLA module, which embedded in Idrisi Kilimanjaro Software. In this process, the MOLA is spatially allocate the land of different categories (objectives) based on number of objectives, objective weights, rank suitability map and area statistics (Eastman, 2012). In this study, for each future decade (such as 2021, 2031), single objective, existing rank suitability map with objective weight equal to 1 and predicted industrial land (estimated using Simple Linear Regression) have been used as the input in MOLA for the future industrial land allocation by resolving the several land allocation conflicts. Thus, industrial growth of the Siltara industrial belt has been predicted for the decade of 2021 and 2031 by integrating Simple Linear Regression and MOLA simulation model.

Accuracy Assessment and Model Validation

The accuracy is a standard parameter used to measures the consistency of results, how close to actual scenario. In this article, 65 to 70 GPS points were collected from field verification using hand handled GPS to check thematic accuracy. The thematic accuracy was calculated using Kappa coefficient method and result is consistent (Overall Kappa =90%) (McCoy, 2006) as per guideline of National Urban Information Systems (National Remote Sensing Agency, 2008). The simulation results has been validate

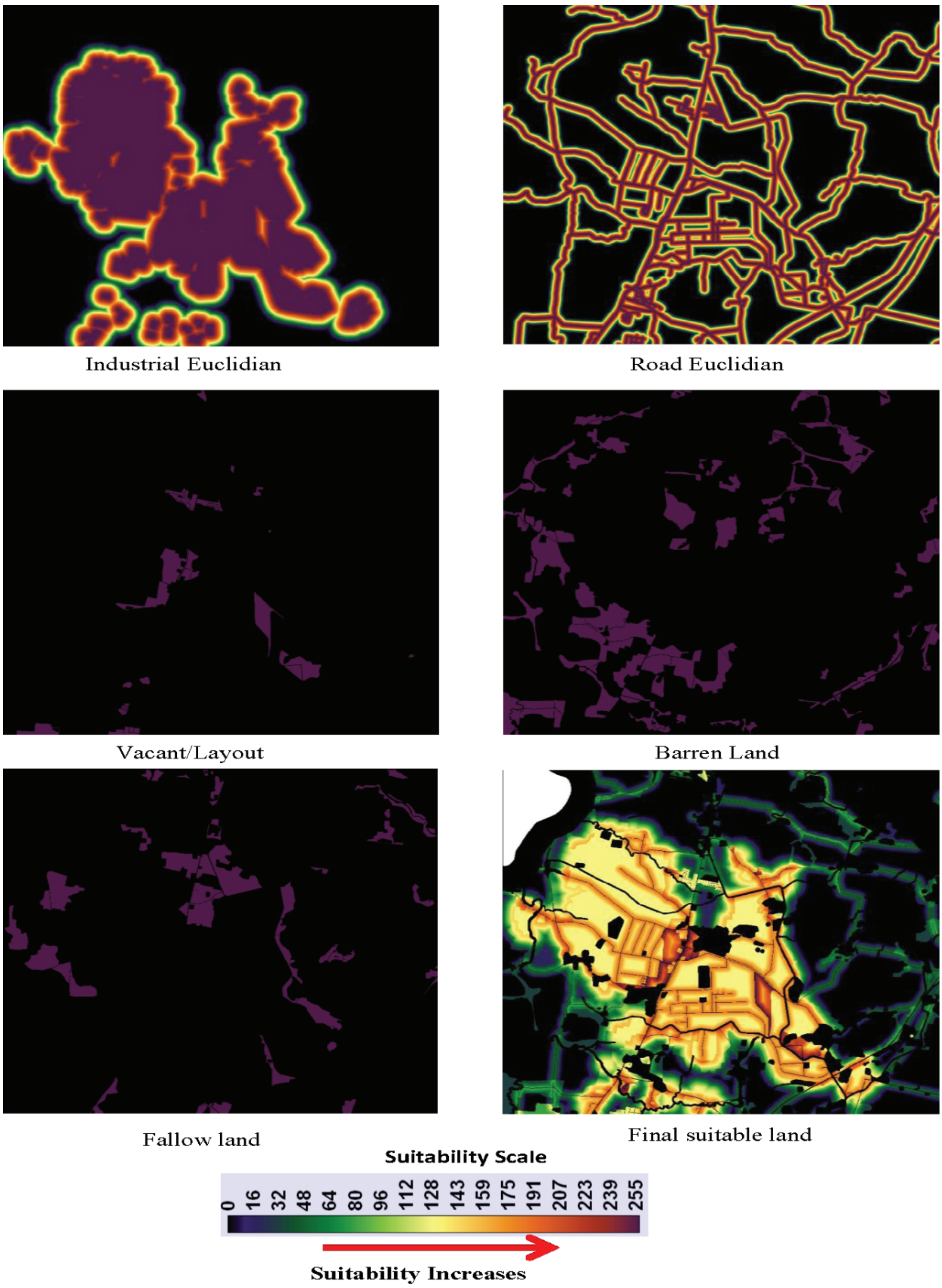

Fig. 3. Land suitability for future industrial growth

using validate and cross tab modules of Idrisi Kilimanjaro software to check the simulation powers of MOLA technique. The results showing that, MOLA has high capability of simulation powers is as 95.35% overall accuracy (K standard or overall accuracy) and locational (K location) accuracy and Kno is 97.24% (Overall Kappa index of no information) (Fig. 6.).

However, this model satisfied 98.63% simulation agreement and 1.37 % simulation disagreement at class level (Fig. 6.).

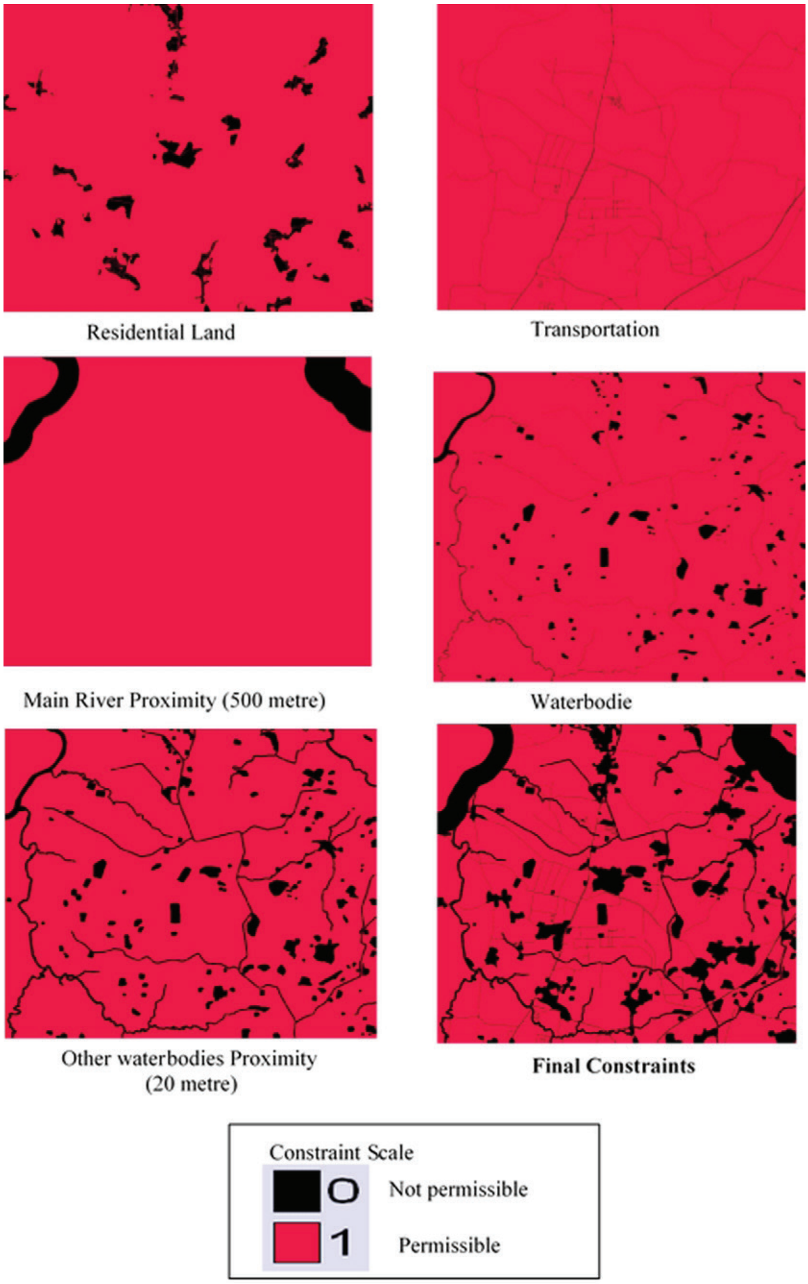

Fig.4. Constraints for Future Industrial Growth Simulation, 2001-2031

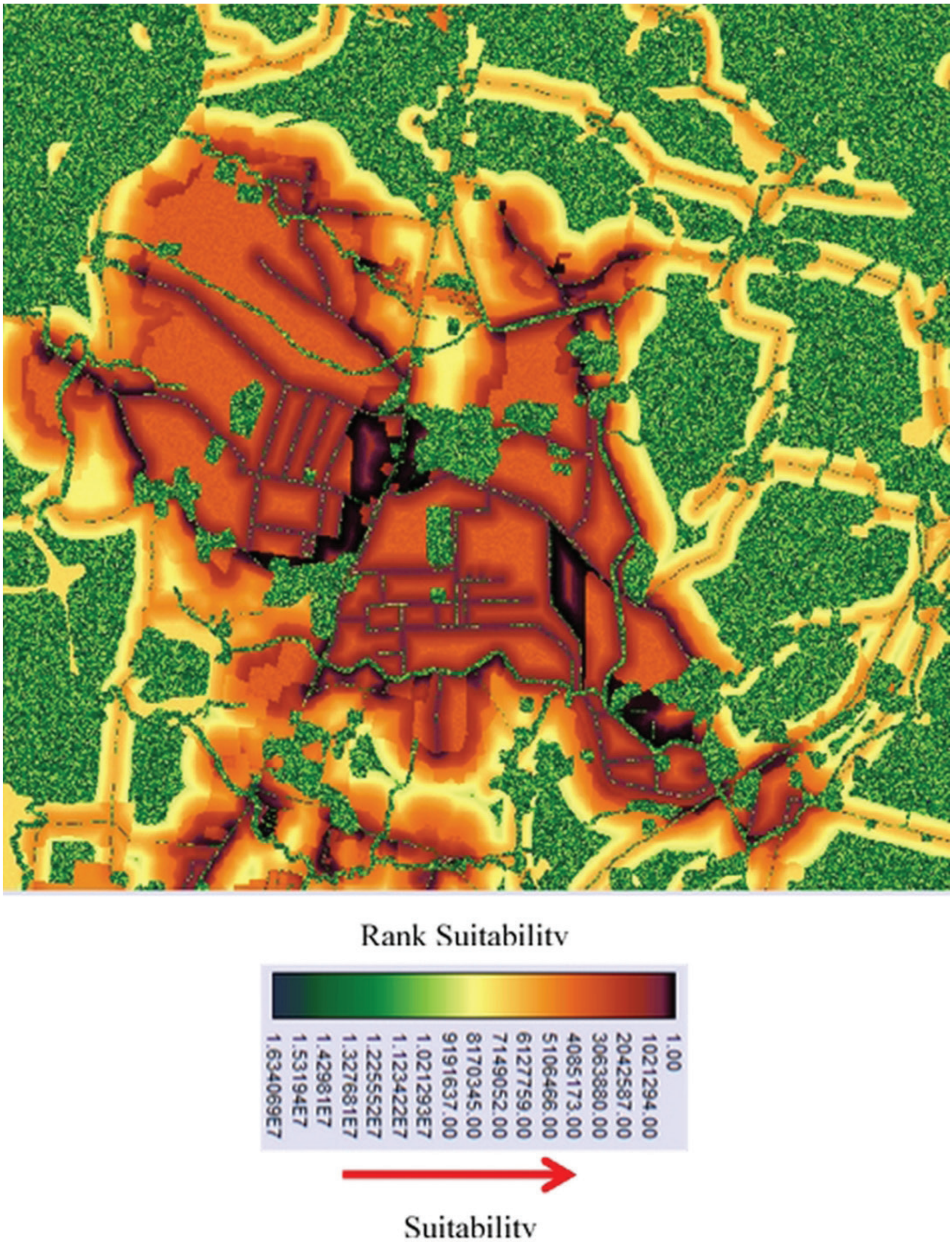

Fig. 5. Rank Suitability for Future Industrial Growth Simulation, 2001-2031

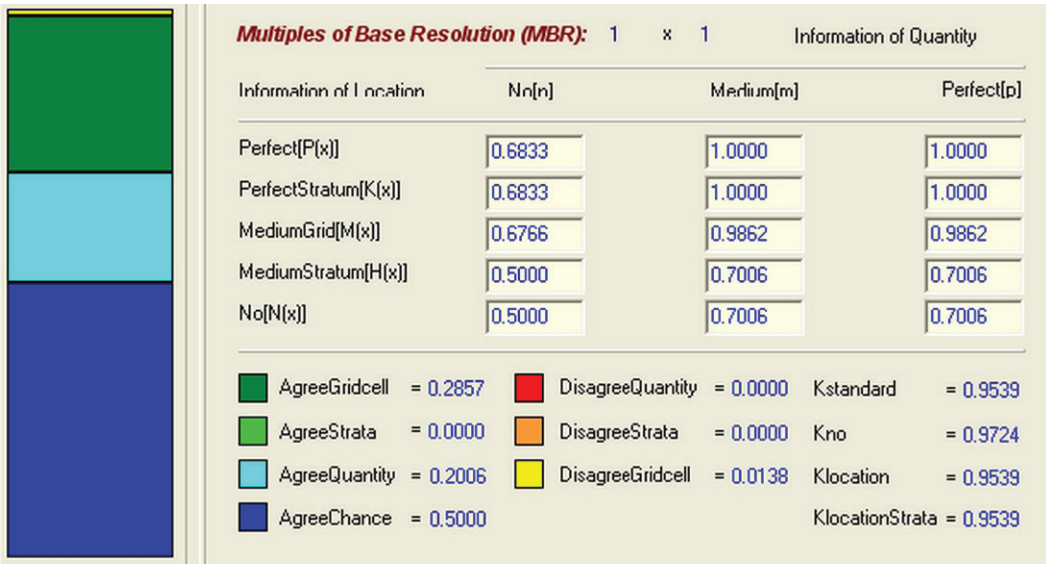

Fig. 6. Validation of simulation result using existing industrial land (2011) and predicted industrial land (2011) using validate module of Idrisi Kilimanjaro Software

5. Results and Discussions

The results of this research work have revealed that the growth of industrial land during past decades was observed more linear than the non-linear and hence SLR model has been applied to predict the future growth of industrial land. This trend of growth showing that the growth of industrial land was very fast as in 2001 was 6.15km2 but is 18.725km2 in 2011 and similarly 31.30 km2 in 2021, 43.87km2 in 2031 due to wide range of suitable condition for industrial setup in terms of physical and cultural suitability (Table 2, Fig.7., Fig. 8.). Although, such suitable conditions are existing in this area yet several political and administrative interferences and land acquisition policy makes it dynamic. In this study area, the land transformation processes are handled by government, industrialist and businessman who are directly or indirectly purchased the agricultural land from the farmers in very cheap rate and transformed into industrial land. Once industries are established in the land surrounded by cropland gradually makes unfertile due to rapid accumulation of industrial dust, polluted materials on such cropland, which rapidly converted into either fallow or barren land with advancement of time.

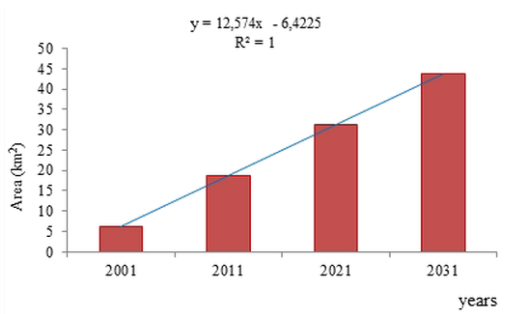

Fig. 7. Growth of industrial land derived using SLR, 2001-2031

Table 2. Growth of Industrial land derived using SLR, 2001-2031

Industrial Land (X)	2001	2011	2021	2031	Total
No. of Pixel (Y)	983974	2995852	5007730	7019608	16007164
Area in sq.km	6.15	18.725	31.30	43.87	100.04
Y=a+bX, a=782786.20, b=201187.8					

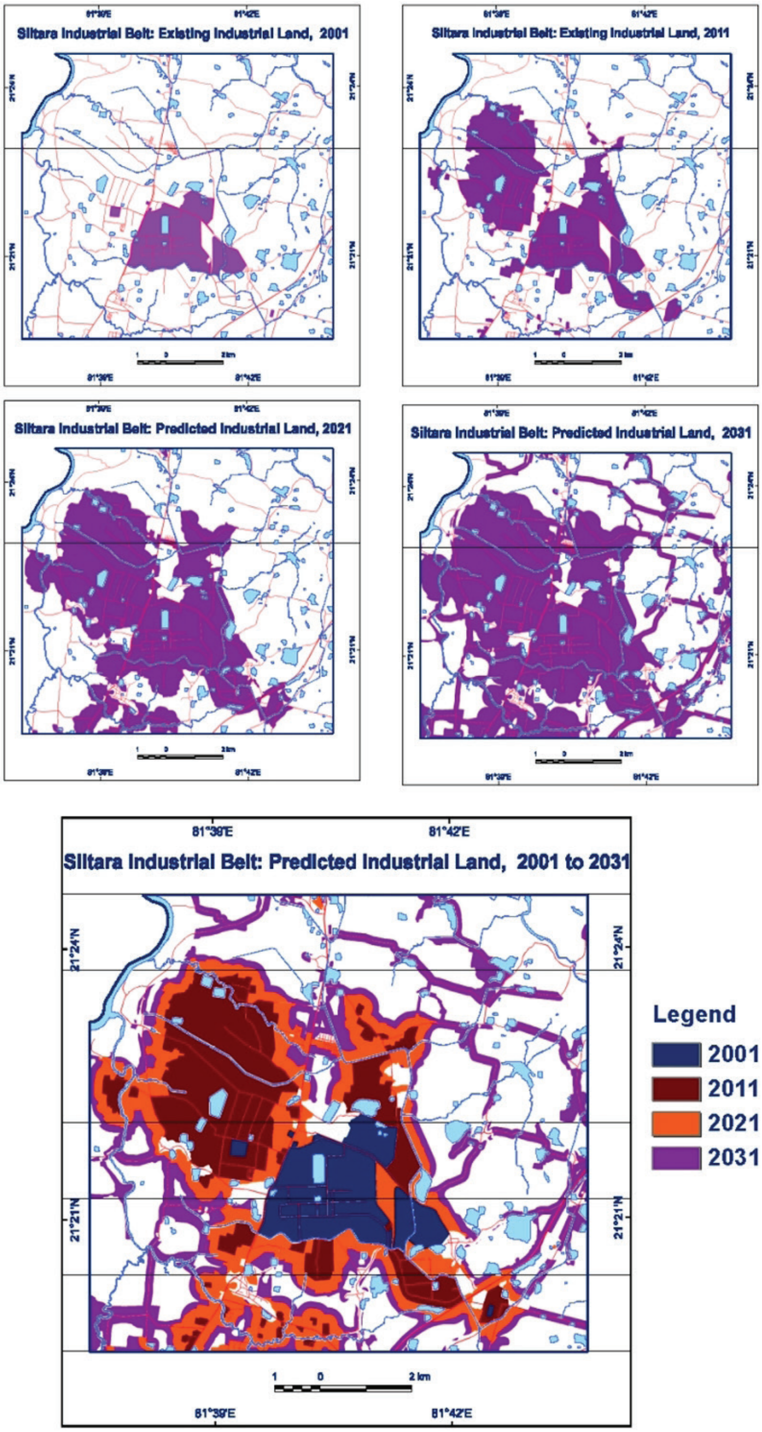

Fig. 8. Simulation of future industrial growth integrating SLR and MOLA, 2001-2031

However, vegetated areas and other grazing land are also affected by the dust coming out from the industrial chimney and reduced its natural growth. The farmers being dissatisfied by the benefits from cropping land they finally sell such unfertile cropland to the businessman or industrialists. Consequently, the growth of industrial land has been rapidly expanding with time.

This, article has noble characteristics because, its reconnects the statistical model with the spatial land allocation model for the future growth simulation of the industrial land without making any conflict. However, this article is incorporated with the high-resolution satellite imageries, advanced decision-making algorithms such as AHP, Fuzzy Membership, MCE, WLC and Boolean Intersection (BI) etc. in the simulation modelling. In this study, the Kappa coefficient and Validate algorithms have been used to assess the accuracy of the model at class level, which resulted that the model has provided very accurate simulation results. Therefore, in this study it has been observed that the integration of SLR and MOLA for the simulation of industrial land has provided real scenarios and better accuracy as we expected for the future growth of the Siltara industrial belt.

6. Conclusion

Results of this work have revealed that industrialization is very rapid in the region after declaration as the state capital because initially the industrial land was 6.15 km^2 (2001) and 18.725 km^2 (2011) and estimated as 31.30 km^2 (2021) and 43.87 km^2 (2031). It is concluded that the accuracy of the model is varied depending on the quality of the data because good data produces better results whereas poor data produced worse results. Therefore, application of this simulation model is not only limited to the forecasting of industrialization but has also wide application on dynamic features, which have spatial characteristics. This model will provide the better opportunities to the planners and policy makers to carry out sustainable development plans and resource management practices through reconnecting various policy interventions.

Acknowledgement

This paper is a part of my Ph.D. thesis. I express my highly gratitude to University Grant Commission, New Delhi, India for financial support and reviewers and editor of the journal for the constructive reviewing of this research paper.

7. References

Ahmed, B. – Ahmed, R. (2012). Modeling Urban Land Cover Growth Dynamics Using Multi-Temporal Satellite Images: A Case Study of Dhaka, Bangladesh. ISPRS International Journal of Geo-Information, 1: pp. 3-31. doi: 10.3390/ijgi1010003

Batty, M. (1997). Cellular Automata and Urban Form: A Primer. Journal of the American Planning Association, 63 (2): pp. 266-274. doi: 10.1080/01944369708975918

Chaitanya, K. (2007). Rapid Economic Growth and Industrialization in India, China & Brazil: at what cost. Working Paper 897. Retrieved from http://webcache.googleusercontent.com/search?q=cache:EVHeVYPWX2gJ:deepblue.lib.umich.edu/bitstream/handle/2027.42/64389/wp897.pdf%3Fsequence%3D1+&cd=2&hl=en&ct=clnk&gl=in

Clarke, K. C. – Gaydos, L. J. (1998). Loose-coupling a cellular automaton model and GIS: long-term urban growth prediction for San Francisco and Washington/Baltimore. International Journal of Geographical Information Science, 12(7): 699-714. doi: 10.1080/136588198241617

Rutten, M. – van Dijk, M. – van Rooij, W. – Hilderink, H. (2013). Land Use Dynamics, Climate Change, and Food Security in Vietnam: A Global-to-local Modeling Approach. World Development, 59: pp. 29-46. doi:10.1016/j.worlddev.2014.01.020

Downing, J. A. – Mcclain, M. – Twilley, R. – Melack, J. M. – Elser, J. – Rabalais, N. N. – Lewis, J. R. – WM, Turner, R. E. – Corredor, J. – Soto, D. – Yanez-Arancibia, A. – Kopaska, J. A. – Howarth, R. W. (1999). The impact of accelerating land-use change on the N-Cycle of tropical aquatic ecosystems: Current conditions and projected changes. Biogeochemistry. 46 (1): pp. 109-148.

doi: 10.1007/BF01007576

Eastman, J. R. (2012). IDRISI Selva manual-manual Version 17.01. Clark University. Worcester, USA.

FAO (2006). Rapid growth of Selected Asian Economics, Lessons and Implications for Agriculture and Food Security. Synthesis Report. http://www.fao.org/docrep/009/ag088e/ag088e00.HTM

Houet, T. – Hubert-Moy, L. (2006). Modeling and Projecting Land-use and Land-cover Changes with a Cellular Automaton in considering Landscape Trajectories. EARSeL eProceedings, European Association of Remote Sensing Laboratorie, 5 (1): pp. 63-76.

Li, J. – Hien, H. M. – Tiwari, P. C. (2011). Analysis on Urban Land-Use Changes and its Impacts on Food Security in Different Asian Cities of Four Developing Countries Using Modified CA Model," APN E-Lib, accessed February 28, 2016, http://www.apn-gcr.org/resources/items/show/1587.

Li, X. – Gar-On, – Yeh, A. (2000). Modelling sustainable urban development by the integration of constrained cellular automata and GIS. International Journal of Geographical Information Science, 14 (2): pp. 131- 152. doi: 10.1080/136588100240886

López, E. – Bocco, G. – Mendoza M. – Duhau, E. (2001). Predicting land-cover and land-use change in the urban fringe: A case in Morelia city, Mexico. Landscape and Urban Planning, 55 (4): pp. 271–285. doi:10.1016/S0169-2046(01)00160-8

Lu, Q. – Liang, F. – Bi, X. – Duffy, R. – Zhao, Z. (2011). Effects of urbanization and industrialization on agricultural land use in Shandong Peninsula of China. Ecological Indicators, 11 (6): pp. 1710-1714. doi:10.1016/j.ecolind.2011.04.026

McCoy, R. M. (2005). Field Method in Remote Sensing. The Guilford Press A Division of Guilford Publications, Inc. 72 Spring Street, New York, NY. USA

Megahed, Y. – Cabral, P. – Silva, J. – Caetano, M. (2015). Land Cover Mapping Analysis and Urban Growth Modelling Using Remote Sensing Techniques in Greater Cairo Region—Egypt. ISPRS International Journal of Geo-Information, 4: pp. 1750-1769. doi: 10.3390/ijgi4031750

Memarian, H. – Balasundram, S. K. – Talib, J. B. – Sung, C. T. B. – Sood, A. M. – Abbaspour, K. (2012). Validation of CA-Markov for Simulation of Land Use and Cover Change in the Langat Basin, Malaysia. Journal of Geographic Information System, 4: pp. 542-554. doi: http://dx.doi.org/10.4236/jgis.2012.46059

Mustak, Sk. (2013). Correction of Atmospheric Haze in Resourcesat-1 LISS-4 Mx Data for Urban Analysis: An Improved Dark Object Subtraction Approach. International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, XL-1/W3, 283-287. doi: 10.5194/isprsarchives-XL-1-W3-283-2013

Mustak, Sk. – Baghmar, N. K. – Singh, S. K. (2015). Land Suitability Modeling for Gram Crop using Remote Sensing and GIS: A Case Study of Seonath Basin, India. Bulletin of Environmental and Scientific Research, 4 (3) (InPress).

National Remote Sensing Agency (2008). National Urban Information Systems (NUIS)-Manual for Thematic Mapping Using High Resolution Satellite Data and Geospatial Techniques. Hyderabad, India: Urban Studies & Geoinformatics Group (RS&GIS Applications Area).

Saaty, T. L. (1980). The Analytical Hierarchy Process. McGraw Hill. New York: USA

Singh, S. K. – Mustak, Sk. – Srivastava, P. K. – Szabó, S. – Islam, T. (2015). Predicting spatial and decadal LULC changes through cellular automata markov chain models using earth observation datasets and geo-information. Environmental Process. 1: pp. 1-18. doi: 10.1007/s40710-015-0062-x

Singh, S. K. – Srivastava, P. K. – Petropoulos, G. – Gupta, M. – Islam, T. (2016) Landscape transform and spatial metrics for mapping spatiotemporal land cover dynamics using Earth Observation data-sets. Geocarto International. DOI: 10.1080/10106049.2015.1130084

Tewolde, M. G. – Cabral, P. (2011). Urban Sprawl Analysis and Modeling in Asmara, Eritrea. Remote Sensing, 3: pp. 2148-2165. doi: 10.3390/rs3102148

Weng, Q. (2002). Land use change analysis in the Zhujiang Delta of China using satellite remote sensing, GIS and stochastic modelling. Journal of Environmental Management, 64, 273–284. doi: 10.1006/jema.2001.0509

Wu, Q. – Li, H. – Wang, R. – Paulussen, J. – He, Y. – Wang, M. – Wang, B. (2006). Monitoring and predicting land use change in Beijing using remote sensing and GIS. Landscape and Urban Planning, 78 (4): pp. 322-333. doi:10.1016/j.landurbplan.2005.10.002